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SOME AXIOMS CONCERNING OCULAR ROTATIONS.*

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A convex sphere set in a concave hemisphere, the two having a common center, the one fitting in the other as shown in Figure 1, can be rotated on any one of its diameters, and only on a diameter, as an axis. The center of curvature, the point to which all the radii converge, is the center of rotation. The point on the surface at which the force is applied determines what the plane of rotation shall be and fixes the axis of rotation at right angles to this plane. This can be best understood by a study of Figure 1.

A B D represents the concave hemisphere whose center is *c*; *a d b e* represents the convex sphere whose center is also *c*. If the force is so applied that *a b* shall be the rotation plane, the axis of rotation will be the diameter *d e*; if the force makes *d e* the rotation plane, then the diameter *a b* becomes the axis of rotation. In like manner, if the force makes *m n* the rotation plane, the diameter *h i* becomes the axis of rotation; and if the force makes *h i* the rotation plane, then the diameter *m n* becomes the axis of rotation. The law governing the rotation of a convex sphere lying loose in a concave hemisphere, the two being concentric, is that the force may be so applied as to make the plane of rotation any

* This paper has been accepted by the executive committee of the Section on Ophthalmology of the American Medical Association, to be presented before the Section at the Boston Session, June 5-8, 1906, and to be published in THE JOURNAL A. M. A. later.

plane that would divide the sphere into two equal parts; that the axis of any rotation must be a diameter at right angles to the rotation plane, and that the common center of all rotations must be the center of curvature. In such a sphere there is no diameter that must be common to every plane of rotation; hence there is no single plane that must contain the axes of all rotations; but every rotation plane and every axis of rotation must

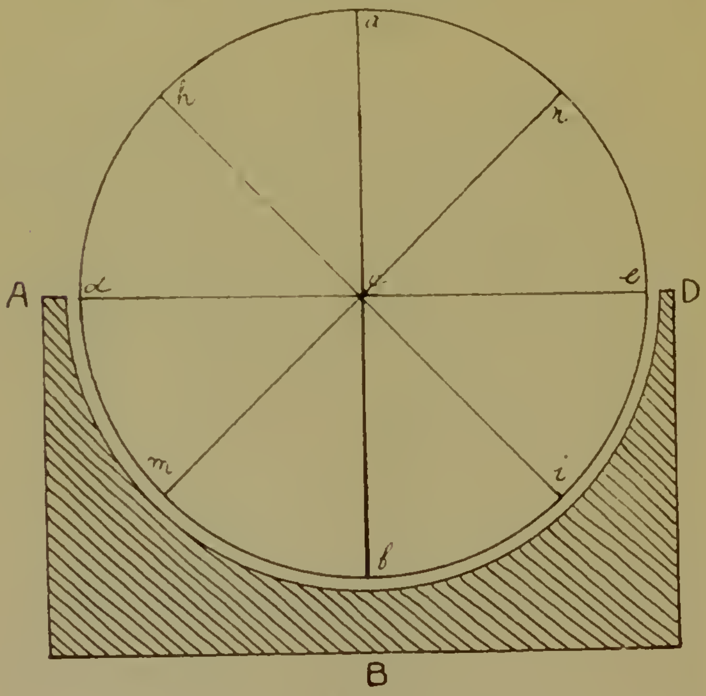

Figure 1.

cut the center of rotation which is the center of curvature.

Figure 2 represents the eye set in its orbit. A B D represents the hemispherical concavity in the bed of fat in which the eye *r d b e* rests. The central point of the macula, *b*, is the point through which all retinal meridians pass; hence it must be the posterior pole; the center of retinal curvature, *c*, is the center of rotation, for through it all diameters pass and only a diameter can

be an axis of rotation. The antero-posterior axis—the optic axis—begins at *b*, the center of the macula, passes through *c*, the center of curvature, thence on to *a*, which point, being 180° from *b*, must be the true anterior pole, for through it the completed meridians would cross. The line *b c a* prolonged from *a* would cut the corneal curve, *s r x*, at *r*, and this point, at or near the center of the cornea, may be called the anterior pole

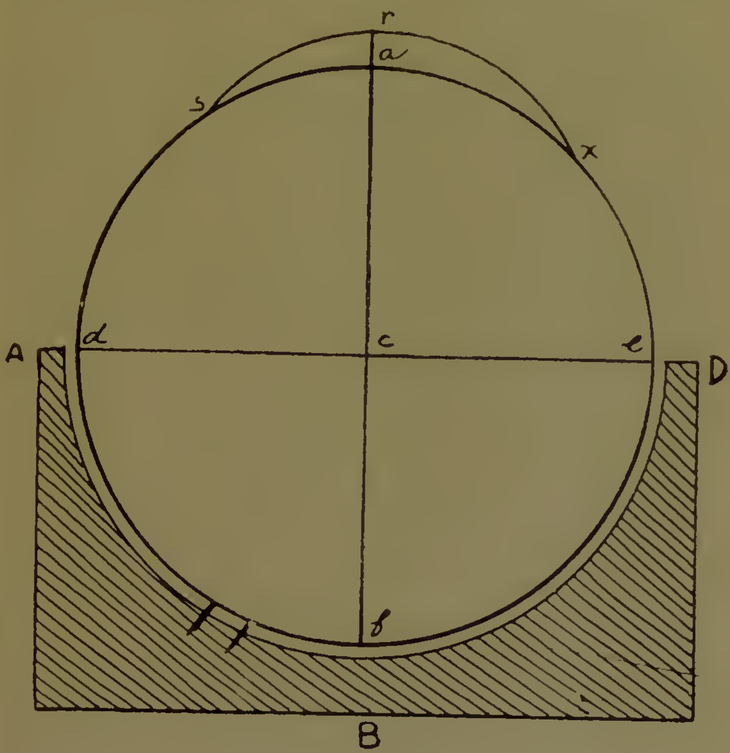

Figure 2.

of the eye, though the real anterior pole, as shown, lies in the aqueous chamber at *a*. The line, *b c a r*, is not only the antero-posterior axis—the optic axis—but it is also the visual axis. The line *d c e* is the transverse axis of the eye and lies in a plane equally distant from the two poles, *b* and *a*, which is the equatorial plane.

Unlike the loose sphere shown in Figure 1, the eye

shown in Figure 2 has a single diameter that must lie in every possible rotation plane, and that line is the visual axis *b c a r*. The purpose of every ocular rotation is that the point of view may be changed, that the visual axis may be rotated so as to bring the macula under another image. That this may be done in the shortest time and with the least expenditure of force, the visual axis is made to move in a plane common to the first and second points of view and the center of rotation. The axis of this rotation must cut the center of rotation and must be at right angles to the rotation plane. The visual axis must lie in every rotation plane, whether the rotation is from the primary to a secondary position, or from one secondary position to another secondary position. Since the visual axis lies in the plane of every possible rotation, all rotation planes must cut the two poles, *b a*. Only meridional planes cut the two poles; hence every plane of rotation of the eye is a meridional plane extended. The only plane cutting the center of rotation at right angles to all the meridional planes is the equatorial plane; hence the equatorial plane contains the axes of all possible rotations.

Every rotation plane of the eye is a fixed plane, for in it lie three fixed points, the center of rotation and the first and second points of view. Every point on any corneo-retinal meridian, other than the one which is the plane of a given rotation, is moved in a plane parallel with the rotation plane; hence ocular rotations must be effected without torsioning. This is true whether the rotation is in one of the four cardinal directions or in any oblique direction.

Under the influence of brain centers the ocular muscles effect all rotations. Their number, their origins and attachments are such as to make every rotation take place in a meridional plane, around an axis lying in the equatorial plane. The ideal eye is rotated in the horizontal plane by only one muscle, either the externus or the internus; in the vertical plane by only two muscles;

if upward, by the superior rectus and inferior oblique; if downward, by the inferior rectus and the superior oblique; in any oblique plane by three muscles, two recti and one oblique. If but one muscle is concerned in a given rotation it is because the rotation plane (the extended meridional plane) bisects the muscle from its origin to its insertion. If two or more muscles must act in a given rotation, it is because their combined action would be the same as the action of a single muscle so related to the eye that the rotation plane would bisect it from origin to insertion. With fewer than six muscles rotations of the eye in all directions could not be effected, and a greater number is not needed.

From one to three cortical brain centers are excited in every ocular rotation, and only cortical centers are excited when there is but one eye. Under the control of one or other of four cortical centers the oblique muscles steady the plane of rotation (a meridional plane) so that it shall bear a fixed relationship to the median and horizontal planes of the head. In doing this the obliques keep the vertical axis of the eye parallel, at all times, with the median plane of the head and compel the transverse axis to lie always in the horizontal plane of the head. This action of the obliques is in the interest of correct orientation.

One, or at most two, of the four cortical verting centers, acting on their respective recti muscles, cause the visual axis to move from one point of view to another in the rotation plane made steady by an oblique, under the influence of one of four cortical centers.

In binocular rotations the cortical centers can make the ocular muscles work in harmony only when the muscles constituting any one of the several pairs are equal in tonicity. Unequal tonicity is provided against by the existence of fusion centers which are basal and under the control of the fusion faculty of the mind. Without these centers it would be impossible for some eyes to have binocular single vision. Unequal tonicity

of muscles necessitates continuous activity on the part of one or more fusion centers in order to prevent diplopia.

When there is equal tonicity of muscles binocular rotations in the four cardinal directions are effected without excitation of the basal or fusion centers. When there is orthophoria every oblique binocular rotation excites two fusion centers, but only during the continuance of such rotation. To illustrate: Rotation of the two eyes obliquely up and to the right is the result of voluntary discharge of neuricity from the first, the fourth and the eighth conjugate centers which call into action, respectively, the two superior recti, the right externus and the left internus, and the right superior oblique and left inferior oblique. The right superior oblique, in preventing a loss of parallelism between the vertical axis of the eye and the median plane of the head, helps the externus, but hinders the superior rectus; the left inferior oblique, in preventing a loss of parallelism between the vertical axis of its eye and the median plane of the head, helps the superior rectus, but hinders the internus. Harmony in this rotation is made possible only by excitation of the right first and left third basal centers.

In binocular rotations each eye must obey the law of monocular rotations as if the other eye had no existence; that is, one, or at most two, of its recti muscles must move the visual axis from the first to the second point of view in a meridional plane made so steady by the action of an oblique muscle that the vertical axis shall not lose parallelism with the median plane of the head—all of this in the interest of correct orientation. But there is another law that must be obeyed by the two eyes in the interest of binocular single vision. This law is enforced whether the eyes are still or in motion, and may be expressed in these words: The two visual axes must lie in a plane common to the point of view and the two centers of rotation, and they must intersect at the point

of view. It is evident that when the eyes are in rotation, up or down or obliquely, this plane is also rotating and that the axis around which it rotates is the line connecting the centers of rotation of the two eyes. In binocular rotations there is an individual rotation plane (a meridional plane) for each eye, along which the visual axis of that eye alone must move from the first to the second point of view, and there is that other plane in which must lie the two visual axes, the two centers of rotation and the two horizontal retinal meridians.

When the head is erect and the two eyes are in their primary positions, this plane, in which the visual axes must lie, becomes the plane of the horopter or monoscopter; and in this position, the eyes being ideal, it coincides with the extended fixed horizontal plane of the head.

When the point of view is directly to the right or left, this plane remains coincident with the fixed horizontal plane of the head and is motionless, while the visual axes are made to move in it to the second point of view.

When the second point of view is directly above or below, this plane is rotated on its only axis, the line connecting the centers of the two eyes, the visual axes remaining stationary in it, provided the first and second points of view are equally distant from the two eyes. The extent of elevation or depression of the second point of view is measured by the angle formed by the intersection of the fixed plane of the head and the rotated horopteric plane, in the axis on which the plane has been rotated. This is true whether the object be directly up or down or at any oblique angle.

In every binocular oblique rotation, above or below the extended fixed horizontal plane of the head, the plane of the horopter must be rotated directly up or down on its only axis until it reaches the second point of view. This is done by the elevator or depressor muscles, as the case may be, but at the same time the lateral recti muscles are making the visual axes move in this

plane toward the objective point, reaching this point at the same time that the horopteric plane is brought to it. Each visual axis, while moving in the horopteric plane, has moved along its own rotation plane (meridional plane extended). That no torsion has occurred is evidenced by the fact that, at the completion of the rotation, the second point of view, the centers of the two eyes and the two horizontal retinal meridians all lie in the rotated horopteric plane. The final result of any oblique binocular rotation is the same as if the visual axes had remained still in the horopteric plane while it was being so rotated as to reach the second point of view;

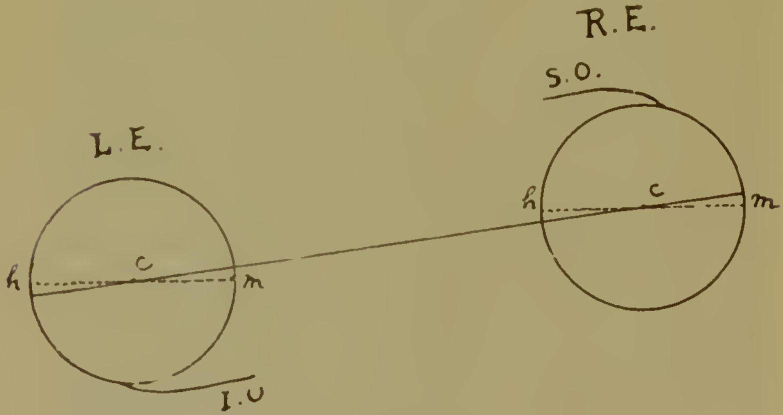

Figure 3.

then this plane having become still, the visual axes had rotated to that point.

The setting of ideal eyes in ideal orbits is such that the horopteric plane, when at rest in the primary position, coincides with the extended fixed horizontal plane of the head. All orbits are not ideal as to height, one often being lower than the other by a fraction of an inch. It is not possible for the horopteric plane of such eyes to be properly related to the extended fixed horizontal plane of the head. The horopteric plane must include the visual axes, the centers of rotation and the horizontal retinal meridians, but the fixed horizontal

plane can not do so if one eye is lower than the other. Figure 3 teaches an evident truth more plainly than simple words could set it forth. The right eye is represented as higher than the left. The line *c c* connecting the two eyes is the only axis around which the horopteric plane can rotate, and lies in that plane. But this plane can be the horopteric plane only on the condition that it must include also the two horizontal retinal meridians and the two visual axes. A glance at Figure 3 shows how the horizontal retinal meridians may be brought into this plane by the action of the eighth conjugate center on the right superior oblique and left inferior oblique. This torsioning makes binocular vision possible, but it makes correct orientation with the two eyes impossible. The figure shows that the inclined plane *c c* can not coincide with the horizontal plane of the head.

It also teaches that, so long as the two eyes are open, the right superior oblique (S O) and the left inferior oblique (I O) must be in a continuous state of contraction, their center, the eighth, being just as continuously active. Rest from this abnormal work can come to either eye only when the other is covered. The left eye covered, as in refraction, allows the eighth center to rest; therefore, the relaxed right superior oblique will let the horizontal retinal meridian leave the plane *c c*, and assume the position *h m*. Likewise, the right eye covered, the eighth center ceases its activity and the relaxed left inferior oblique allows the horizontal meridian to leave the plane *c c* and assume position *h m*. Astigmatic corrections for such eyes will be faulty unless the axes of the cylinders are shifted in harmony with the necessary binocular torsioning. Eyes that are not level are eyes that can never be made strong, although the proper correction of focal errors may help them. Of such eyes it may be said: "One eye is better than two," however free from focal error and muscle imbalance.

Eyes are never torted except in the interest of binocular single vision, and even then it is at the expense of correct orientation. There are but two conditions that cause torsioning: First, when one eye is higher than the other, there must be a torsioning of both eyes in the same direction, as shown in Figure 3; second, in non-parallel oblique astigmatism, there must be torsioning of the two eyes, but in opposite directions. The first kind of torsioning makes an horopteric plane possible; in the second kind of torsioning there is binocular single vision, but there can be no horopteric plane. The correction of astigmatic eyes that are normally set relieves the torsioning and makes the true horopteric plane possible.

All that has been said in this paper pertains to eyes whose muscles have normal tonicity; but it has been shown that there are abnormal conditions of the eyes in which the normal muscles do abnormal work.

Heterophoric eyes can not have binocular single vision and correct orientation unless the weaker muscle of an unbalanced pair shall receive supplemental power from a reserve brain center—the fusion center for that muscle. To relieve the fusion centers of abnormal activity, and so to relate the two eyes that there may be volitional obedience to the laws governing binocular rotations, the ideal thing to do is to give equal tonicity to the opposing muscles of every pair.

In ocular rotation the visual axis, which is the chief line of direction, being a diameter of the eye, takes the position of other diameters in succession until, finally, it reaches the second point of view. The diameter of the eye that pointed to the second point of view, before the rotation began, must have connected that point and its retinal image, hence must have been the visual line, or line of direction, for that retinal point. All lines of direction, or visual lines, cross the visual axis at the

center of retinal curvature, and are radii of retinal curvature prolonged.

Error in location of the posterior pole of the eye not only led to error in teaching as to ocular rotations, but it also led to error in teaching as to the law of direction. Lines of direction are not the axial rays of light, but they are radii of retinal curvature prolonged.

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CHICAGO:
PRESS OF THE AMERICAN MEDICAL ASSOCIATION,
ONE HUNDRED AND THREE DEARBORN AVENUE,
1906.